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Akihisa HONGO et al.

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METHOD AND APPARATUS FOR
FORMING INTERCONNECTS, AND
POLISHING LIQUID AND POLISHING
METHOD

VERIFYING DECLARATION

Honorable Commissioner of Patents and Trademarks

Washington, D.C. 20231

Sir:

I, Ryoji Kosugi, declare and say:

that I am thoroughly conversant in both the Japanese and English languages;

that I am presently engaged as a translator in these languages;

that the attached document represents a true English translation of Japanese
Patent Application No. 2001-077154 filed on March 16, 2001.

I further declare that all statements made herein of my own knowledge are true
and that all statements made on information and belief are believed to be true; and
further that these statements were made with the knowledge that willful false statements
and like so made are punishable by fine or imprisonment, or both, under Section 1001 of
Title 18 of the United States Code, and that such willful false statements may jeopardize
the validity of the application or any patent issuing thereon.

Signed this 23rd day of October, 2003

Ryoji Kosugi

TRANSLATOR

PATENT OFFICE
JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

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Application Number: Patent Application No. 2001-077154

Applicant(s): EBARA CORPORATION

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(TITLE OF THE INVENTION) METHOD AND APPARATUS FOR FORMING
INTERCONNECTS

(CLAIMS)

(CLAIM 1) An apparatus for forming interconnects by forming a copper film on a surface of a substrate to fill copper into fine recesses formed in the surface of the substrate, comprising:

a housing;

a transport route provided in said housing for transporting the substrate; and

a copper-plating section, an electrolytic or chemical polishing section, and an annealing section which are disposed along said transport route.

(CLAIM 2) The apparatus according to claim 1, further comprising a cleaning section for cleaning the substrate.

(CLAIM 3) The apparatus according to claim 1 or 2, wherein at least two of said electrolytic or chemical polishing sections are provided for carrying out a first-stage electrolytic or chemical polishing and a second-stage electrolytic or chemical polishing.

(CLAIM 4) The apparatus according to any one of claims 1 through 3, further comprising a cap-plating treatment section for forming a protective film which selectively covers and protects the exposed surface of copper interconnects in said housing.

(CLAIM 5) A method for forming interconnects by forming a copper film on a surface of a substrate to fill copper

into fine recesses formed in the surface of the substrate, comprising the steps of:

plating the substrate with copper to form the copper film on the surface of the substrate;

electrolytic or chemical polishing the surface of the substrate having the copper film thereon in a polishing liquid; and

annealing the substrate in such a state that the copper film remains on the entire surface of the substrate, after said polishing.

(DETAILED DESCRIPTION OF THE INVENTION)

(0001)

(TECHNICAL FIELD TO WHICH THE INVENTION BELONGS)

This invention relates to a method and an apparatus for forming interconnects, and more particularly to a method and an apparatus for forming interconnects by embedding a copper (Cu) in recesses for interconnects formed in the surface of a semiconductor substrate.

(0002)

(PRIOR ART)

In recent years, instead of using aluminum or aluminum alloys as a material for forming interconnection circuits on a semiconductor substrate, there is an eminent movement towards using copper (Cu) which has a low electric resistivity and high electro-migration endureance. Copper interconnects are generally formed by filling copper into fine recesses formed in the surface of a substrate. There are known various techniques for producing such copper

interconnects, including CVD, sputtering, and plating. According to any such technique, a copper is deposited on the substantially entire surface of a substrate, followed by removal of unnecessary copper by chemical mechanical polishing (CMP).

(0003)

FIGS. 18(a) through (c) illustrate, in a sequence of process steps, an example of producing such a substrate W having copper interconnects. As shown in FIG. 18(a), an oxide SiO_2 or of a film of low-K material 2 is deposited on a conductive layer 1a formed on a semiconductor base 1 bearing semiconductor devices. A contact hole 3 and a trench 4 for interconnects are formed in the oxide film 2 by the lithography/etching technique. Thereafter, a barrier layer 5 of TaN or the like is formed on the entire surface, and a seed layer 7 as an electric feed layer for electroplating is formed on the barrier layer 5.

(0004)

Then, as shown in FIG. 18(b), copper plating is carried out onto the surface of the substrate W to fill the contact hole 3 and the trench 4 with copper and, at the same time, deposit a copper film 6 on the oxide film 2. Thereafter, the copper film 6 on the oxide film 2 is removed by chemical mechanical polishing (CMP) so as to make the surface of the copper film 6 filled in the contact hole 3 and the trench 4 for interconnects, and the surface of the oxide film 2 lie substantially on the same plane. An interconnect composed of the copper film 6, as shown in FIG. 18(c), is thus formed.

(0005)

(PROBLEM TO BE SOLVED BY THE INVENTION)

By the way, as shown in FIG. 19, when the copper film 6 is formed by plating on the surface of the substrate W in which a fine hole(s) 8 with a diameter d_1 , e.g., of the order of $0.2 \mu m$, and a large hole(s) 9 with a diameter d_2 , e.g., of the order of $100 \mu m$ are present, the growth of plating is likely to be promoted at the portion above the fine hole 8 whereby the copper film 6 is raised at that portion, even when the effect of a plating liquid or an additive contained in the plating liquid is optimized, whereas the growth of plating with an adequately high levelling property cannot be made within the large hole 9. This results in a difference $(a+b)$ in the level of the copper film 6 deposited on the substrate W, i.e. the height a of the raised portion above the fine hole 8 plus the depth b of the depressed portion above the large hole 9. Thus, in order to obtain the desired flat surface of substrate W with the fine hole 8 and the large hole 9 being fully filled with copper, it is necessary to provide the copper film 6 having a sufficiently large thickness beforehand, and remove by CMP the extra portion corresponding to the above difference $(a+b)$ in the level.

(0006)

This involves problems that the large thickness of the plated film requires a prolonged time for processing by CMP in order to polish away the large amount. Increasing the rate of CMP processing to avoid the prolongation of

processing time can cause dishing in the large hole during CMP processing.

(0007)

In order to solve the above problems, it is required to make the thickness of the plated film as thin as possible, and prevent the formation of the raised and depressed portions in the plated film, despite the co-presence of fine and large holes in the surface of the substrate, thereby improving the flatness of the plated film. In this regard, when the plating treatment is carried out in an electrolytic copper sulfate bath, for example, it has not been possible to decrease both of the rise and the depression in the plated film merely by the action of the plating liquid or of an additive. It is possible to reduce the degree of rise in the plated film by temporary using a reversed electric field as a power source, or by using a PR pulse power source during the film deposition process. This approach, however, cannot prevent the formation of depressed portions and, in addition, denatures the property of the film at its surface portion.

(0008)

Further, there is a strong demand for not resorting to CMP processing which, in general, needs a complicated operation and control, takes a considerably long processing time, and in addition, may be carried out, in general, in a separate apparatus from that of a plating treatment.

It is to be pointed out that though a low-K material, which has a low dielectric constant, is expected to be

predominantly used in the future as a material for an insulating film, the low-K material has a low mechanical strength and therefore is hard to endure the stress applied during CMP processing. Thus, there is a demand for a method which enables the flattening of the substrate without giving stress thereto.

Further, a method has been reported which carries out CMP processing simultaneously with plating, viz. chemical mechanical electrolytic polishing. According to this method, the mechanical processing is carried out to the growing surface of plating to promote the growing defect of plating, causing the problem of denaturing of the resulting film.

(0009)

The present invention has been made in view of the above drawbacks in the prior art. It is therefore a object of the present invention to provide a method and apparatus for forming interconnects which, while omitting a CMP treatment entirely or reducing a load upon a CMP treatment to the least possible extent, can successively carry out a series of copper interconnects-forming steps including a copper-filling step.

(0010)

(MEANS FOR SOLVING THE PROBLEMS)

According to the present invention defined in claim 1, there is provided an apparatus for forming interconnects by forming a copper film on a surface of a substrate to fill copper into fine recesses formed in the surface of the substrate, comprising: a housing; a transport route provided

in said housing for transporting the substrate; and a copper-plating section, an electrolytic or chemical polishing section, and an annealing section which are disposed along said transport route.

(0011)

According to this apparatus, the flattening process after copper plating is carried out mainly by means of electrolytic or chemical polishing. Thus, the apparatus can omit a CMP treatment entirely or reduce a load upon a CMP treatment, and can successively carry out a series of flattening steps including annealing in the same housing.

(0012)

According to the present invention defined in claim 2, there is provided the apparatus according to claim 1, further comprising a cleaning section for cleaning the substrate.

(0013)

According to the present invention defined in claim 3, there is provided the apparatus according to claim 1 or 2, wherein at least two of said electrolytic or chemical polishing sections are provided for carrying out a first-stage electrolytic or chemical polishing and a second-stage electrolytic or chemical polishing.

This enables such two-stage electrolytic or chemical polishing treatment to the surface of copper that the rate of polishing or the polishing selectivity to the base is made different between the first and the second stages so as to obtain a flatter copper surface, or that the surface of

copper is polished in the first stage, and in the second stage, the exposed copper and other conductive materials (e.g. TaN) are polished evenly at the same polishing rate.

(0014)

According to the present invention defined in claim 4, there is provided the apparatus according to any one of claims 1 through 3, further comprising a cap-plating treatment section for forming a protective film which selectively covers and protects the exposed surface of copper interconnects in the housing.

The cap-plating treatment for protecting the exposed surface of copper interconnects by the selective coating of a protective film thereon can thus be carried out successively in the same housing.

(0015)

According to the present invention defined in claim 5, there is provided a method for forming interconnects by forming a copper film on a surface of a substrate to fill copper into fine recesses formed in the surface of the substrate, comprising the steps of: plating the substrate with copper to form the copper film on the surface of the substrate; electrolytic or chemical polishing the surface of the substrate having the copper film thereon in a polishing liquid; and annealing the substrate in such a state that the copper film remains on the entire surface of the substrate, after said polishing.

(0016)

(EMBODIMENTS OF THE INVENTION)

Preferred embodiments of the present invention will now be described with reference to the drawings.

FIG. 1 is a plan view showing an embodiment of an interconnects-forming apparatus in accordance with the present invention. The interconnects-forming apparatus comprises a housing 10 that houses the following: loading/unloading sections 11; a copper-plating section 12, a cleaning/drying section 14, an annealing section 16, a first electrolytic or chemical polishing section 18, a second electrolytic or chemical polishing section 20 and a cleaning/drying section 22, which are arranged in the above order from the opposite end of the loading/unloading sections; and a cap-plating treatment section 24 including a pretreatment section 24a, a Pd-attaching treatment section 24b, a pre-plating treatment section 24c, an electroless CoWP-plating section 24d and a cleaning/drying section 24e, which are arranged on the opposite end of above sections. Further, the apparatus is provided with a transporting device 26 movable along the transport route 25 for transporting a substrate between the above sections.

(0017)

As shown in FIG. 2, the plating section 12 includes a top-opened cylindrical plating tank 32 for accommodating a plating liquid 30, and a substrate holder 34 for detachably holding a substrate W with its front surface facing downward at such a position that the substrate W covers the top opening of the plating tank 32. In the inside of the plating tank 32, an anode plate 36 in a flat plate shape,

which makes an anode electrode when immersed in the plating liquid 30 with the substrate as a cathode plate, is disposed horizontally. The center portion of the bottom of the plating tank 32 is connected to a plating liquid injection pipe 38 for spurting a plating liquid upwardly to form a jet flow. Further, a plating liquid receiver 40 is provided around the upper outer periphery of the plating tank 32.

(0018)

In operation, a substrate W held with its front surface facing downward by the substrate holder 34 is positioned above the plating tank 32 and a given voltage is applied between the anode plate 36 (anode) and the substrate W (cathode) while the plating liquid 30 is allowed to spurt upwardly from the plating liquid injection pipe 38 so that the jet flow of the plating liquid 30 hits vertically against the lower surface (to be plated surface) of the substrate W, whereby a plating current is allowed to pass between the anode plate 36 and the substrate W, and a plated film is thus formed on the lower surface of the substrate W.

(0019)

As shown in FIG. 3, electrolytic or chemical polishing sections 18 and 20 include a top-opened cylindrical etching tank 52 for accommodating an polishing liquid (an electrolyte or a chemical agent), and a substrate holder 56 for detachably holding the substrate W with its front surface facing downward by a holding member 54, such as an electrostatic chuck, at such a position that the substrate W covers the top opening of the polishing tank 52. In the

inside of the polishing tank 52, a plate 58 in a flat plate shape, which makes a cathode when immersed in the polishing liquid 50 with the substrate as an anode, is disposed horizontally. The substrate holder 56, at its center, is connected to the lower end of a drive shaft 62 that is connected to a motor 62, so that it is allowed to rotate together with the substrate W. The plate 58 is connected to one end of a reciprocating rod 66 which is driven by an actuator 64 such as a cylinder, so that it is allowed to reciprocate horizontally by the actuation of the actuator 64.

(0020)

In operation, while the lower surface (polishing surface) of the substrate W, which is held with its front surface facing downward by the substrate holder 56, is kept in contact with the polishing liquid 50, the substrate W is allowed to rotate together with the substrate holder 56 and, at the time, the plate 58 is allowed to reciprocate; while a given voltage is applied between the plate 58 (cathode) and the substrate W (anode) to pass an electric current therebetween so as to electrolytically polish a plated film formed on the substrate W, whereas a chemical polishing is effected by stopping the electric current.

(0021)

Thus, in the electrolytic or chemical polishing sections 18 and 20, the surface of the substrate W can be chemically polished merely by immersing the substrate surface in the polishing liquid (a chemical agent) due to the corrosion effect of the polishing liquid, whereas the

surface of the substrate W can be electrolytically polishing by immersing the plate 58 and the substrate W in the polishing liquid (an electrolyte), and applying a given voltage therebetween.

(0022)

FIG. 4 shows another embodiment of electrolytic or chemical polishing sections 18, 20 which employ a plate 58 having a larger diameter than that of the substrate W. The plate 58 is connected at its center to the upper end of a drive shaft 70 that is connected to a motor 68, so that it is allowed to rotate by the actuation of the motor 68.

(0023)

Next, an interconnects-forming process will now be described by referring to FIGS. 5 and 6. This example illustrates a case where the surface of the substrate W, which is plated with copper to form a plated copper film 6 as shown in FIG. 18(b), is flattened without resorting to a CMP processing to thereby form copper interconnects, and the surface of the copper interconnects is subjected to a cap-plating treatment.

(0024)

First, the substrate W having a seed layer 7 (see FIG. 18(a)) as an outermost layer is taken out one by one from the loading/unloading section 11 by the transport device 26, and is transported to the copper-plating section 12 (step 1).

(0025)

Next, plating with copper by e.g. electroplating is carried out onto the substrate W in the copper-plating

section 12, thereby forming a plated copper film 6 on the surface of the substrate W as shown in FIG. 6(a) (step 2). In carrying out the plating, with a primary view to reducing a depression in the plated copper film caused by the presence of the large hole, there is used, as the plating liquid 30 shown in FIG. 2, of a plating liquid having a high bottom-up composition with a high copper sulfate concentration and a low sulfuric acid concentration, e.g. a composition of 100-300 g/l of copper sulfate and 10-100 g/l of sulfuric acid. An additive for improving the bottom-up property may be added to the plating liquid. By the term "bottom-up property" is herein meant a property of inducing a bottom-up growth of plating in the large hole.

(0026)

After the completion of plating, the plated substrate W is transported to the cleaning/drying section 14 for cleaning and drying (step 3), and the substrate W is then transported to the annealing section 16 where the substrate W having the plated copper film 6 thereon is heat-treated to anneal the copper film 6 (step 4). Thereafter, the annealed substrate W is transported to the first electrolytic or chemical polishing section 18.

(0027)

Next, in the first electrolytic or chemical polishing section 18, a first-stage electrolytic or chemical polishing is carried out to the surface (plated surface) of the substrate W to polish and remove the copper film 6 formed on the surface of the substrate W (step 5). In the case of the

electrolytic polishing, a polishing liquid is used, as the polishing liquid (electrolyte) 50 shown in FIGS. 3 and 4, which comprises at least one inorganic acid and/or organic acid capable of dissolving copper and at least one thickening agent selected from the group consisting of polyhydric alcohols, high-molecular weight polyhydric alcohols and alkylene glycol alkyl or aryl ethers, and which thus has an increased viscosity by the addition of the thickening agent.

(0028)

The use of such a polishing liquid 50 having an increased viscosity in the electrolytic polishing of the surface of the copper film 6 formed on the substrate W can enlarge the diffusion layer on the surface of the substrate, and therefore can raise the polarization potential and suppress the conductivity of the entire surface of the substrate in the liquid, thereby suppressing the dissolution of copper over the entire substrate surface and making the surface not sensitive to a minute change in current density, whereby a polished surface endowed with high flatness can be obtained. In this regard, the enlargement of the diffusion layer, the rise in polarization potential and the suppression of conductivity depend largely on the viscosity of the polishing liquid, and the use of the above polishing liquid having an increased viscosity can provide an improved flatness to the polished surface. For obtaining a sufficiently high flatness, the polishing liquid 50 preferably has a viscosity of 10 cP (0.1 Pa·s) or more and

a conductivity of 20 mS/cm or lower. The temperature of the polishing liquid 50 is preferably 30°C or lower, especially 25°C or lower.

(0029)

The above electrolytic polishing removes the seed layer 7 on the barrier layer 5 as well as the copper film 6 on the seed layer 7 to thereby expose the surface of the barrier layer 5, and flattens the exposed surface of the barrier layer 5 together with the surface of the copper film 6 filled in the contact hole 3 and the trench 4 for interconnects, as shown in FIG. 6(b), and then the electrolytic polishing process is completed. The electrolytic polishing, during the processing, may be switched to a chemical polishing in the same treatment section.

(0030)

Phosphoric acid may be mentioned as an example of the inorganic acid capable of dissolving copper. Examples of the organic acid capable of dissolving copper may include citric acid, oxalic acid and gluconic acid. Examples of the polyhydric alcohols as the thickening agent include ethylene glycol, propylene glycol and glycerin. Examples of the high-molecular weight polyhydric alcohols as the thickening agent include polyethylene glycol and polypropylene glycol. Examples of the alkylene glycol alkyl or aryl ethers as the thickening agent include ethylene glycol ethyl ether, ethylene glycol methyl ether, ethylene glycol propyl ether, ethylene glycol phenyl ether, propylene glycol ethyl ether,

propylene glycol methyl ether, propylene glycol phenyl ether and dipropylene glycol monomethyl ether.

(0031)

A pulse waveform or a PR pulse waveform may be employed as the waveform pulse of the electric current applied in the electrolytic polishing. The use of such a pulse waveform can improve the diffusion of the additive contained in the polishing liquid.

(0032)

FIGS. 7 through 9 show the experimental results of electrolytic or chemical polishing carried out by using various polishing liquids. FIG. 7 shows the relationship between the viscosity and conductivity of a polishing liquid and the polishing effect; FIG. 8 shows the relationship between the liquid temperature and the polishing effect; and FIG. 9 shows the relationship between the waveform of current and the polishing effect. In these Figures, a-1, a-2, c-1 and c-2 denote the following charge conditions shown in Table 1.

(0033)

Table 1

a-1	DC	5 A/dm ²
a-2	DC	10 A/dm ²
c-1	Pulse	5A/dm ² X 10 mS OFF X 10 mS
c-2	Pulse	10 A/dm ² X 10 mS OFF X 10 mS

FIG. 7 shows the results of a polishing experiment in which various polishing liquids, which mutually consist of phosphoric acid as a base liquid, dipropylene glycol monomethyl ether as a thickening agent, and water, but have different viscosities due to different contents of the water, were used. As can be seen from FIG. 7, the polishing effect increases with an increase in the liquid viscosity and with a decrease in the liquid conductivity, and the polishing effect index shows its peak at the viscosity 20-60 cP and the conductivity 17-9 mS/cm.

(0034)

FIG. 8 shows the results of a polishing experiment in which polishing liquids, which mutually consist of 100 ml of phosphoric acid, 150 ml of dipropylene glycol monomethyl ether and 150 ml of water, but differ in the liquid temperature, were used. It can be seen from FIG. 8 that the

polishing effect varies with the various electrolytic conditions employed, and shows a high effect at the liquid temperature of 30°C or lower, especially 25°C or lower.

(0035)

FIG. 9 shows the results of a polishing experiment in which a polishing liquid consisting of 100 ml of phosphoric acid, 150ml of dipropylene glycol monomethyl ether and 50ml of water, was used and the pulse waveform was varied. In FIG. 9, 10/10 sec indicates 10 sec at ON and 10 sec at OFF. FIG. 9 shows that a pulse waveform of 1-20 mS ON/OFF, is preferred.

(0036)

During the polishing process, in the case of the electrical or chemical polishing section 18 shown in FIG. 3, the substrate W is allowed to rotate while the plate 58 is allowed to reciprocate. In the case of electrolytic or chemical polishing section 18 shown in FIG. 4, the substrate W and the plate 58 are both allowed to rotate in the same direction. In either case, the substrate W and the plate 58 are thus made to move relatively so as to make the velocities of the substrate at its various points relative to the plate 58 closer to one another, thereby making the flow conditions of the polishing liquid between the various points of the substrate and the plate 58 uniform so as not to make a singular point in the flow of polishing liquid. This can prevent the plated film on the substrate W from being locally etched excessively to worsen the flatness of the substrate surface. This holds also for the subsequent

electrolytic or chemical polishing carried out in the second electrolytic or chemical polishing section.

(0037)

The substrate, which has undergone the first-stage electrolytic or chemical polishing treatment in the first electrolytic or chemical polishing section 18, is then transported to the second electrolytic or chemical polishing section 20 where the second-stage electrolytic or chemical polishing is carried out to the surface of the substrate (step 6). In case a chemical polishing is carried out as the second-stage polishing, a polishing liquid is used as the polishing liquid (chemical agent) which comprises the polishing liquid having an increased viscosity used in the first electrolytic or chemical polishing (step 5) and added thereto, an additive which can adhere to the surface of copper and chemically suppress the dissolution of copper, or a basic liquid or additive which forms a strong complex with copper or promotes the formation of a passivated film on the surface of copper.

(0038)

Electrolytic or chemical polishing of the surface of copper film 6 and the surface of the barrier film 5 composed of a conductive material, such as TaN, by the use of the above polishing liquid containing the basic liquid or the additive, can polish the copper film 6 and the barrier film (TaN) 5 evenly at the same polishing rate. The polishing treatment thus removes the barrier layer 5 on the oxide film 2, and flattens the exposed surface of the oxide film 2

together with the surface of the copper film 6 filled in the contact hole 3 and the trench 4 for interconnects, as shown in FIG. 6(c), and then the second-stage electrolytic or chemical polishing process is completed.

(0039)

Specific examples of the additive which can electrochemically suppress the dissolution of copper may include imidazole, benzimidazole, benzotriazole and phenacetin. Chromic acid may be mentioned as an example of the basic liquid which promotes the formation of a passivated film on the surface of copper. ETDA and quinaldin may be mentioned as examples of the additive, for forming a strong complex with copper, and pyrophosphoric acid may be mentioned as an example of the basic liquid, for forming a strong complex with copper.

(0040)

As described above, the electrolytic and/or chemical polishing treatment can effectively remove the unnecessary copper film 6 on the an oxide film or a film of low-K material 2, together with the barrier film 5, and can successfully flatten the surface of the oxide film 2 and the surface of the copper film 6 filled in the contact hole 3 and the trench 4 for interconnects. A CMP treatment can therefore be omitted.

(0041)

After the completion of the second-stage electrolytic or chemical treatment, the substrate W is transported to the cleaning/drying section 22 for cleaning and drying (step 7),

and is then transported to the pretreatment section 24a in the cap-plating treatment section 24, where the substrate is subjected to a pretreatment (step 8). Then, in the Pd-attaching treatment section 24, Pd is attached to the surface of the copper film 6 to activate the exposed surface of the copper film 6 (step 9). The substrate is then subjected to a pre-plating treatment in the pre-plating treatment section 24c (step 10). Thereafter, the substrate is transported to the electroless CoWP-plating section 24d, where selective electroless plating with CoWP is carried out onto the activated surface of the copper film 6 so as to cover and protect the exposed surface of the copper film 6 with a CoWP film P as shown in FIG. 6(d) (step 11).

(0042)

After the completion of the cap-plating treatment, the substrate W is transported to the cleaning/drying section 24e for cleaning and drying (step 12), and the substrate W is then returned to the cassette of the loading/unloading section 11 by the transporting device 26 (step 13).

Though the selective electroless CoWP plating have been described above as an example of the cap-plating treatment which is carried out onto the activated exposed surface by attaching Pd, in advance, of the copper film 6 with a CoWP film selectively, the cap-plating treatment of the present invention, of course, is not limited to this specific example.

(0043)

As shown in FIG. 10, it is preferred in the present invention to additionally carry out a chemical polishing or an electrolytic polishing (step 5-1) between the electrolytic or chemical polishing of step 5 and the electrolytic or chemical polishing of step 6, and a chemical polishing or a composite electrolytic polishing (step 6-1) between the electrolytic or chemical polishing of step 6 and cleaning/drying treatment of step 7.

(0044)

In this regard, there is a case where in the electrolytic polishing of the surface of the substrate W for removing the copper film 6 formed thereon (step 5), a copper 6a still remains unremoved on the barrier film 5, as shown in FIG. 11(a), due to the polishing conditions, etc. If the electrolytic polishing is continued to such a substrate, only the copper in the hole and the trench for interconnects is polished whereas the copper 6a on the barrier film is left unremoved.

(0045)

In order to overcome the drawback in the above case, the electrolytic polishing (step 6) can be shifted to a chemical polishing (step 6-1) by shutting off the power source to stop applying a given voltage between the plate 58 and the substrate W, and by using the polishing liquid used in the electrolytic polishing as a chemical agent, whereby the copper 6a remaining on the surface of the barrier layer 5 can be removed as shown in FIG. 11(b).

(0046)

Though the electrolytic polishing (step 6) and the chemical polishing (step 6-1) are carried out in the same polishing tank using the same polishing liquid in the above example, it is also possible to carry out a polishing in a separate polishing tank, either by a chemical polishing using e.g. a polishing liquid (chemical agent) containing an additive which, due to the inhibitor effect of the additive that preferentially adheres to a high-current density area, can preferentially remove the remaining copper-film 6a, or by an electrolytic polishing using the same polishing liquid (electrolyte). Imidazole, benzimidazole, benzotriazole or phenacetin may be used as the additive.

(0047)

Further, there is also a case where after the chemical or electrolytic polishing of the surface of the substrate W for removing the barrier layer 5 and the copper film 6 (step 6), a conductive material 5a such as TaN, which is the material of the barrier layer 5, still remains on the oxide film or a film of a low-K material 2, as shown in FIG. 11(c), due to the polishing conditions, etc. This necessitates an additional processing by CMP, that is, a CMP treatment cannot be omitted.

(0048)

In order to overcome the drawback in the above case, electrolytic or chemical polishing is carried out using a polishing liquid containing an additive which has a higher inhibitor effect than the above described additive added to the electrolyte used in the preceding electrolytic polishing

(step 5), or electrolytic polishing is carried out using a basic liquid which can passivate copper or under passivating electrolytic conditions, thereby flattening the surface of the oxide film or a film of low-K material (insulating film) 2 and the surface of the copper film 6 filled in the contact hole 3 and the trench for interconnects, as shown in FIG. 6(c).

(0049)

Instead of such electrolytic or chemical polishing, composite electrolytic polishing may be carried out by passivating the entire surface of the copper layer 6 and the remaining barrier film 6 composed of a conductive material such as TaN, and polishing and removing both the copper and the conductive material at the same time. It is also possible to first carry out the electrolytic or chemical polishing, and subsequently carry out such a composite electrolytic polishing.

(0050)

The composite electrolytic polishing can be carried out by using a polishing liquid containing abrasive particles. As shown in FIG. 12, the abrasive particles G polish and remove protuberances P of the passivated copper or TaN remaining on the surface of the substrate W, and the barrier layer 5 composed of a conductive material such as TaN is preferentially polished and removed by electrolytic or chemical polishing. The copper and the conductive material such as TaN can thus be polished at the same time. When a finish surface of a surface roughness of 100 Å or less is

desired, for example, it is preferred to use an abrasive of a #5000 size or smaller.

(0051)

FIG. 13 is a plan view of yet another embodiment of an interconnects-forming apparatus in accordance with the present invention. The interconnects-forming apparatus comprises a housing 10 that houses the following: loading/unloading sections 11; transport route 25; a copper-plating section 12, a cleaning/drying section 14, a first electrolytic or chemical polishing section 18, a second electrolytic or chemical polishing section 20, a cleaning/drying section 22 and an annealing section 16, which are arranged in the above order from the opposite side of the loading/unloading sections 11. Further, the apparatus is provided with a transporting device 26 movable along the transport route 25 for transporting a substrate between the above sections. The constructions of the copper-plating section 12, the electrolytic or chemical sections 18 and 20, etc. are the same as described above.

(0052)

An example of the process for forming interconnects will now be described by referring to FIG. 14. This example illustrates a case where the surface of the substrate W, which is plated with copper to form a plated copper film 6 as shown in FIG. 18(b), is flattened through a CMP processing to form copper interconnects. Though the final flattening process is thus carried out by CMP, a load upon the CMP is reduced.

(0053)

First, the substrate W having a seed layer 7 (see FIG. 18(a)) as an outermost layer is taken one by one from the loading/unloading section 11 by the transport device 26, and is transported to the copper-plating section 12 (step 1).

(0054)

Next, plating with copper by e.g. electroplating is carried out onto the substrate W in the copper-plating section 12, thereby forming a plated copper film 6 (see FIG. 18(b)) on the surface of the substrate W (step 2). After the completion of plating, the plated substrate W is transported to the cleaning/drying section 14 for cleaning and drying (step 3), and the substrate W is then transported to the first electrolytic or chemical polishing section 18.

(0055)

Next, in the first electrolytic or chemical polishing section 18, a first-stage electrolytic or chemical polishing is carried out to the surface (plated surface) of the substrate W to polish and remove the copper film 6 formed on the surface of the substrate W (step 4). In the case of the electrolytic polishing, as described above, a polishing liquid is used as the polishing liquid (electrolyte) 50 shown in FIGS. 3 and 4 which comprises at least one inorganic acid and/or organic acid capable of dissolving copper and at least one thickening agent selected from the group consisting of polyhydric alcohols, high-molecular weight polyhydric alcohols and alkylene glycol alkyl or aryl ethers, and which thus has an increased viscosity by the

addition of the thickening agent, thereby enlarging the diffusion layer on the surface of the substrate, raising the polarization potential and suppressing the conductivity of the entire surface of the substrate in the liquid, to thereby obtain a high flatness of the polished surface.

(0056)

Next, the substrate which has undergone the first-stage electrolytic polishing treatment is transported to the second electrolytic or chemical polishing section 20 where the second-stage electrolytic or chemical polishing is carried out to the surface of the substrate (step 5). As described above, in case a chemical polishing is carried out as the second-stage polishing, a polishing liquid is used as the polishing liquid (chemical agent) which comprises the polishing liquid having an increased viscosity used in the electrolytic polishing and added thereto, an additive which can adhere to the surface of copper and chemically suppress the dissolution of copper, or a basic liquid or a additive which forms a strong complex with copper or promotes the formation of a passivated film on the surface of copper, thereby further improving the flatness of the copper film 6 (see FIG. 18(b)). The chemical polishing treatment may be omitted.

(0057)

As described above, instead of the chemical polishing, an electrolytic polishing may be carried out by using the same polishing liquid containing the same additive. Further, the chemical polishing may be carried out using the same

polishing liquid as used in the preceding electrolytic polishing (step 4), by shutting off the power source for the electrolytic polishing. When the thickness of the copper film 6 has reached the minimum thickness necessary for annealing, e.g. 300 nm, the chemical polishing is terminated, and the substrate is then transported to the cleaning/drying section 22.

(0058)

The substrate is cleaned and dried in the cleaning/drying section 22 (step 6), and is then transported to the annealing section 16 where the substrate having the plated film 6 thereon is heat-treated to anneal the copper film 6 (step 7). Thereafter, the annealed substrate W is returned to the cassette of the loading/unloading section 11 by the transporting device 26 (step 8).

(0059)

Thereafter, the substrate W is subjected to a CMP treatment in a separate apparatus (step 9) to make the surface of the copper film 6 filled in the contact hole 3 and the trench 4 for interconnects and the surface of the oxide film 2 lie substantially on the same plane, thereby forming interconnects composed of the copper film 6 (see FIG. 18(c)). If necessary, the above described cap-plating treatment is then carried out (step 10).

(0060)

According to this embodiment, the flatness of the copper film on a substrate after electrolytic or chemical polishing can be improved, even when fine holes and large

holes are co-present in the surface of the substrate, by either carrying out one stage of the electrolytic polishing, or carrying out at least two stages of the electrolytic polishing and the electrolytic or chemical polishing. A later CMP processing can therefore be carried out in a short time without suffering from dishing.

(0061)

In order to make the plated surface of the substrate as flat as possible by the electrolytic polishing, it is important to hold the substrate with its best flattened state and use a plate (cathode) having the flattest possible finish, and also to allow them to move relatively while they are kept as close as possible so as not make, within the area of the substrate surface, any singular points in the flow of polishing liquid and in the electric field.

(0062)

FIGS. 15 and 16 show yet another embodiment of electrolytic or chemical polishing sections 18, 20 which meet the above demands. The polishing section 18 (20) includes a top-opened cylindrical polishing tank 52 for accommodating a polishing liquid 50, and a substrate holder 56 for detachably holding a substrate W with its front surface facing downward at such a position that the substrate W covers the top opening of the polishing tank 52.

(0063)

The etching tank 52 comprises a substantially discoidal bottom plate 72, a cylindrical overflow weir 74 fixed to the peripheral end of the bottom plate 72, and an outer shell 78

surrounding the outer periphery of the overflow weir 74 and defining an polishing liquid drainage zone 76 between itself and the overflow weir 74. A plate (cathode plate) 58 in a plain plate shape, which makes a cathode when immersed in the polishing liquid 50, is disposed horizontally on the upper surface of the bottom plate 72 of the etching tank 52.

(0064)

A cylindrical boss 72a is connected integrally to the central portion of the lower surface of the bottom plate 72 of the etching tank 52, and the boss 72a is rotatably mounted, through a bearing 80, on a crank portion 82a located at the upper end of a rotating shaft 82. Thus, the central axis O_1 of the crank portion 82a is eccentric to the central axis O_2 of the rotating shaft 82 with an eccentricity e , whereas the central axis O_1 of the crank portion 82a coincides with the central axis of the boss 72a. The rotating shaft 82 is rotatably mounted, through bearings 85a, 85b, on the outer shell 78. Though not shown in drawings, rotation-prevention mechanisms for preventing rotation of the bottom plate 72 about its own axis are provided between the bottom plate 72 and the outer shell 78.

(0065)

When the rotating shaft 82 is rotated, the crank portion 82a is allowed to make a revolutionary movement with the eccentricity e as a radius, and the revolutionary movement of the crank portion 82a causes the bottom plate 72 to make, together with the plate 58, a scroll movement (translational rotation) with the eccentricity e as radius,

i.e., a revolutionary movement with the eccentricity e as a radius, with rotation about its own axis being inhibited.

(0066)

As shown in FIG. 16, the diameter d_3 of the plate 58 is determined so that even when the substrate W of diameter d_4 makes a scroll movement, the substrate W does not move out of the area of the plate 58; and the diameter d_5 of the polishing liquid feed zone, which contains the below-described polishing liquid feed holes 58b, is determined so that even when the substrate W of diameter d_5 makes a scroll movement, the polishing liquid feed zone remains within the area of the substrate W.

(0067)

The bottom plate 72 is provided, in its inside, with a polishing liquid chamber 72b communicated with an polishing liquid feed line 88 extending from a circulation tank 84 and including midway a pressure pump 86, and a plurality of polishing liquid discharge holes 72c extending upwardly from the polishing liquid chamber 72b. The circulation tank 84 communicates with the polishing liquid drainage zone 76 through a return line 90.

(0068)

When the plate 58 is used in the electrolytic polishing of a plated copper film, it is made of such material as titanium that forms an oxide thereof on the surface of the plate, whose oxide has a poor adhesion to copper. When the electroetching is carried out onto a plated copper film by using such a plate, the dissolved copper ions are

precipitated onto the plate 58 (cathode) side, but the precipitate is immediately released from the plate 58 due to the poor adhesion between copper and the plate 58, and the released precipitate comes to float as copper particles in the polishing liquid. Further, the generation of hydrogen gas during the etching process can be prevented. The electrolytic polishing can thus provide the etched surface with excellent flatness.

(0069)

In the surface of the plate 58, there are formed a number of grooves 58a extending linearly over the full length of the plate 58 in a lattice form, and in the inside of the plate 58, a plurality of polishing liquid feed holes 58b, each disposed correspond to each polishing liquid discharge hole 72c and communicated with the groove 58a, are provided.

(0070)

During the electroetching, the polishing liquid is fed from the grooves 58a formed in the surface of the plate 58 to between the two electrodes, i.e. the plate 58 and the substrate W, while particles floating in the polishing liquid is allowed to pass through the grooves 58a to the outside smoothly by the action of centrifugal force. This makes it possible that a fresh polishing liquid is always present between the electrodes. Further, selection for the plate 58 of such material as titanium, whose oxide formed on the surface exhibits poor adhesion to copper, in carrying out the electroetching of a plated copper film makes it

possible that the copper, once precipitated onto the plate side from its dissolved ion state, is immediately released from the plate 58 to float as copper particles in the polishing liquid. The polishing liquid containing such copper particles is, allowed to pass through the grooves 58a and flow smoothly to the outside. This prevents the deterioration with time of the surface flatness of the plate 58, thus ensuring the flatness of the plate 58.

(0071)

In order to prevent making a difference in current density between the center and the periphery of the plate 58 and also to allow the polishing liquid 50 to flow smoothly through the grooves 58a, the grooves 58a are preferably formed in a lattice arrangement when the substrate W makes a scroll movement; and when the substrate W makes a reciprocating movement, the grooves 58a are preferably arranged in parallel in the movement direction.

(0072)

The substrate holder 56 is housed in a under-opened housing 92, and is designed to be capable of moving up and down by a lifting rod 94, and rotating together with the housing 92 through a motor 60. The substrate holder 56, in its inside, is provided with a vacuum chamber 56a that communicates with a vacuum source, and a number of vacuum attraction holes 56b penetrating downwardly from the vacuum chamber 56a. The substrate holder 56 is thus constructed to hold the substrate W in a vacuum attraction manner.

(0073)

Usually, small undulations are present on the substrate W. Further, the substrate can further deform depending on how it is held. With such a deformed substrate, it is generally not possible to flatten with $0.1 \mu m$ or less of irregularity. According to the vacuum attraction method herein employed, the substrate W is held with its entire surface being kept attracted, whereby the undulations present on the substrate can be absorbed and thus the substrate can be held with a flatter state. Accordingly, it becomes possible to obtain flatness of less than $0.1 \mu m$ irregularity by the electroetching treatment.

An electrostatic chucking manner for holding the substrate may be adopted instead of the vacuum attraction manner.

(0074)

When the substrate W held by the substrate holder 56 is lowered down to a position for etching treatment, the distance S between the lower surface of the substrate W and the upper surface of the plate 58 should be made as small as possible mechanically, preferably is 1.0 mm or less, more preferably 0.5 mm or less. By thus making the anode-cathode distance S as small as possible mechanically, i.e., preferably 1.0 mm or less and more preferably 0.5 mm or less, the concentration of electric current on the raised portions on the surface of the substrate W, which are to be preferentially etched, is promoted, and a vertical electric field can be formed between the substrate W and the plate 58, whereby the entire surface (plated surface) of the substrate

W can be successfully etched into an evenly flattened surface.

(0075)

In the housing 92, electric contacts 96 are provided which, when the substrate W is attracted and held by the substrate W, contact with the bevel portion or the peripheral portion of the substrate W to make the substrate anode. Further, a packing 98 is provided on the lower surface of the substrate holder 56 which, when the substrate W is held by the holder, makes a pressure contact with the upper surface of the substrate for sealing.

(0076)

Next, operations for carrying out electrolytic polishing in the chemical polishing sections 18, 20 will now be described.

First, the polishing liquid 50 is fed into the etching tank 52 and, while the polishing liquid 50 is overflowing from the overflow weir 74, the bottom plate 72 is allowed to make, together with the plate 58, a scroll movement. Under these conditions, as described above, the substrate holder 56 holding the substrate W with its plated surface facing downward is lowered, while rotating the substrate W, down to a position for electro etching.

(0077)

The relative movement between the substrate W and plate 58 makes the velocities of the substrate W at its various points relative to the plate 58 closer to one another so as to make the flow conditions of the polishing liquid 50

between the various points of the substrate W and the plate 58 uniform, that is to say, so as not make a singular point in the flow of polishing liquid.

(0078)

Under the above conditions, a pulse current as shown in FIG. 17, for example, with a time t_1 to be applied of 1 mSec-20mSec, preferably 10 mSec, and with a current density to be applied of 2-20 A/dm², is applied a plurality of times with stoppage times t_2 , each time t_2 equal to the time t_1 , for example, being interposed. Upon passing of current, oxidation dissolution of the plated film occurs first at the raised portion of the substrate, and then shifts to the plane portion. Accordingly, passing of current and immediate shutoff of the power feed, when repeated, enables selective etching of the raised portion.

(0079)

The polishing liquid is fed from the grooves 58a formed in the surface of the plate 58 to between the two electrodes, i.e. the plate 58 and the substrate W, while particles floating in the polishing liquid is allowed to pass through the grooves 58a to the outside smoothly by the action of centrifugal force, whereby a fresh polishing liquid is always present between the electrodes. Selection for the plate 58 of such material as titanium, whose oxide formed on the surface exhibits poor adhesion to copper, in carrying out the electro etching of a plated copper film makes it possible that the copper, once precipitated onto the plate side from its dissolved ion state, is immediately released

from the plate 58 to float as copper particles in the polishing liquid. The polishing liquid containing such copper particles is, allowed to pass through the grooves 58a and flow smoothly to the outside. This prevents the deterioration with time of the surface flatness of the plate 58, thus ensuring the flatness of the plate 58. Moreover, since the anode-cathode distance S can thus be kept constant during the operation and the generation of hydrogen gas can be prevented, the electro etching can provide the etched surface with excellent flatness.

(0080)

(EFFECTS OF THE INVENTION)

According to the present invention, as described above, the flattening process after copper plating is carried out mainly by means of electrolytic or chemical polishing. Thus, the apparatus can omit a CMP treatment entirely or reduce a load upon a CMP treatment, and can successively carry out a series of flattening steps including annealing in the same housing with the exception of the case where the final flattening process is carried out by CMP.

(BRIEF DESCRIPTION OF THE DRAWINGS)

(FIG. 1)

FIG. 1 is a plan view of an embodiment of an interconnects-forming apparatus in accordance with the present invention.

(FIG. 2)

FIG. 2 is a schematic view of a copper-plating section used in the apparatus of FIG. 1.

(FIG. 3)

FIG. 3 is a schematic view of an electrolytic or chemical polishing section used in the apparatus of FIG. 1.

(FIG. 4)

FIG. 4 is a schematic view of another embodiment of an electrolytic or chemical polishing section.

(FIG. 5)

FIG. 5 is a flow diagram showing the flow of process steps in the interconnects-forming apparatus of FIG. 1.

(FIG. 6)

FIG. 6 is a cross-sectional view illustrating steps of the formation of copper interconnects according to the process flow of FIG. 5.

(FIG. 7)

FIG. 7 is a graph showing the relationship between the viscosity and conductivity of a polishing liquid and the polishing effect in an electrolytic or chemical polishing using the polishing liquid.

(FIG. 8)

FIG. 8 is a graph showing the relationship between the liquid temperature and the polishing effect in an electrolytic or chemical polishing using the polishing liquid.

(FIG. 9)

FIG. 9 is a graph showing the relationship between the waveform of current and the polishing effect in an electrolytic or chemical polishing using the polishing liquid.

(FIG. 10)

FIG. 10 is a diagram showing the flow of process steps that are to be added to the process steps of FIG. 2.

(FIG. 11)

FIG. 11 is a cross-sectional view illustrating the formation of copper interconnects according to the process flow of FIG. 10.

(FIG. 12)

FIG. 12 is a diagram illustrating a composite electrolytic polishing.

(FIG. 13)

FIG. 13 is a plan view of another embodiment of an interconnects-forming apparatus in accordance with the present invention.

(FIG. 14)

FIG. 14 is a flow diagram showing the flow of process steps in the apparatus of FIG. 13.

(FIG. 15)

FIG. 15 is a cross-sectional view of yet another embodiment of an electrolytic or chemical polishing section.

(FIG. 16)

FIG. 16 is a plan view of a plate used in the electrolytic or chemical polishing section of FIG. 15.

(FIG. 17)

FIG. 17 is a diagram showing an example of a current pulse to be applied in the electrolytic or chemical polishing section of FIG. 15.

(FIG. 18)

FIGS. 18 is a cross-sectional view illustrating, in a sequence of process steps, the formation of copper interconnects through copper plating.

(FIG. 19)

FIG. 19 is a cross-sectional view illustrating the state of a substrate having a problem which has been plated with copper according to a conventional method.

(DESCRIPTION OF THE REFERENCE NUMERALS AND SIGNS)

- 2 oxide film
- 3 contact hole
- 4 trench
- 5 barrier layer
- 5a conductive material
- 6 copper film
- 6a copper
- 7 seed layer
- 10 housing
- 11 loading/unloading sections
- 12 copper-plating section
- 14, 22 cleaning/drying section
- 16 annealing section
- 18, 20 electrolytic or chemical polishing section
- 24 cap-plating treatment section
- 25 transport route
- 26 transporting device
- 30 plating liquid
- 32 plating tank
- 50 polishing liquid

52 polishing tank

(NAME OF DOCUMENT) ABSTRACT

(ABSTRACT)

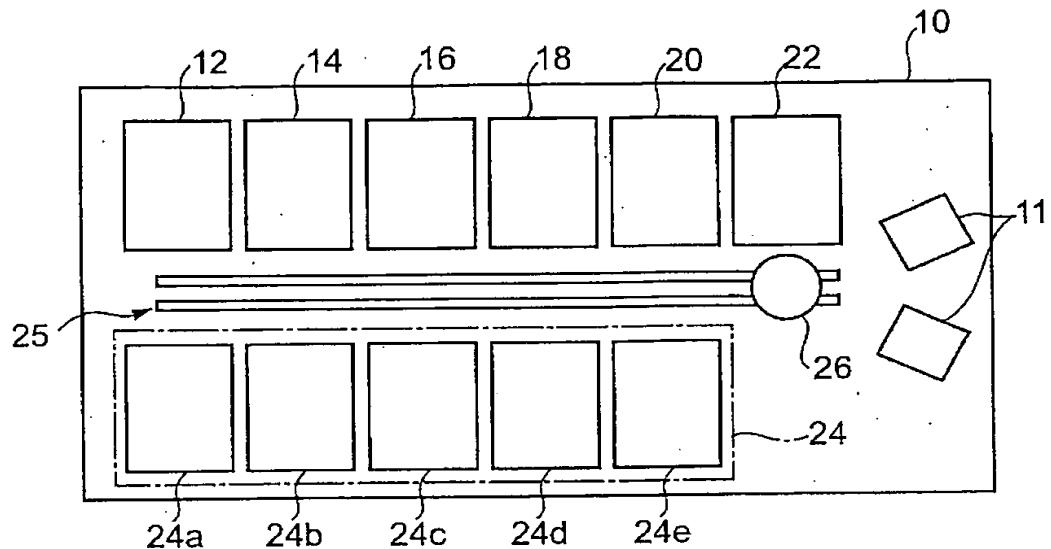
(PROBLEM) The present invention provides a method and apparatus for forming interconnects which, while omitting a CMP treatment entirely or reducing a load upon a CMP treatment to the least possible extent, can successively carry out a series of copper interconnects-forming steps including a copper-filling step.

(MEANS FOR RESOLUTION) An apparatus for forming interconnects by forming a copper film on a surface of a substrate to fill copper into fine recesses formed in the surface of the substrate, comprising: a housing 10; a transport route 25 provided in the housing 10 for transporting the substrate; and a copper-plating section 12, an electrolytic or chemical polishing section 18, 20, and an annealing section 16 which are disposed along said transport route 25.

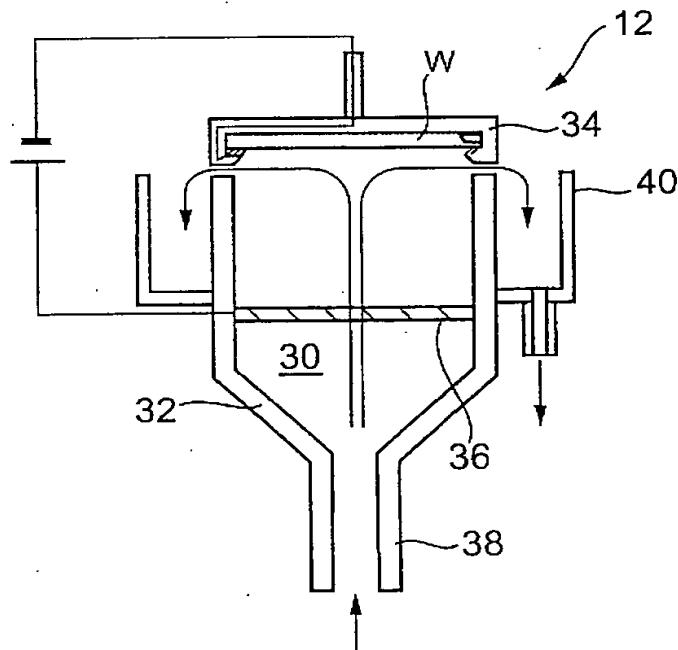
(Selected Figure) Fig. 1

(NAME OF DOCUMENT) DRAWINGS

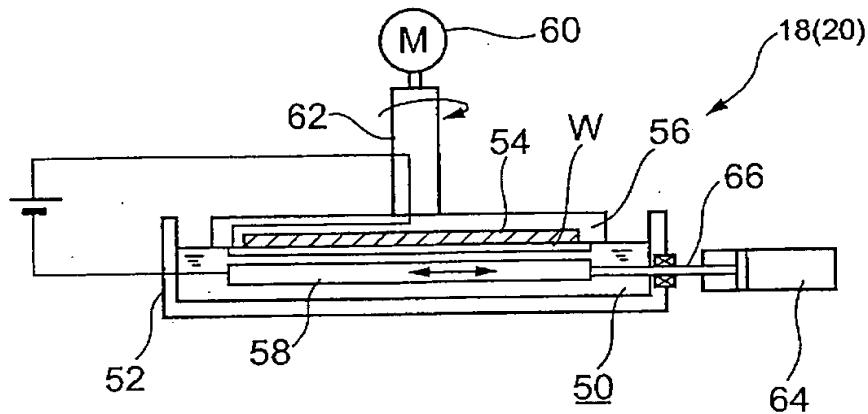
(FIG. 1)



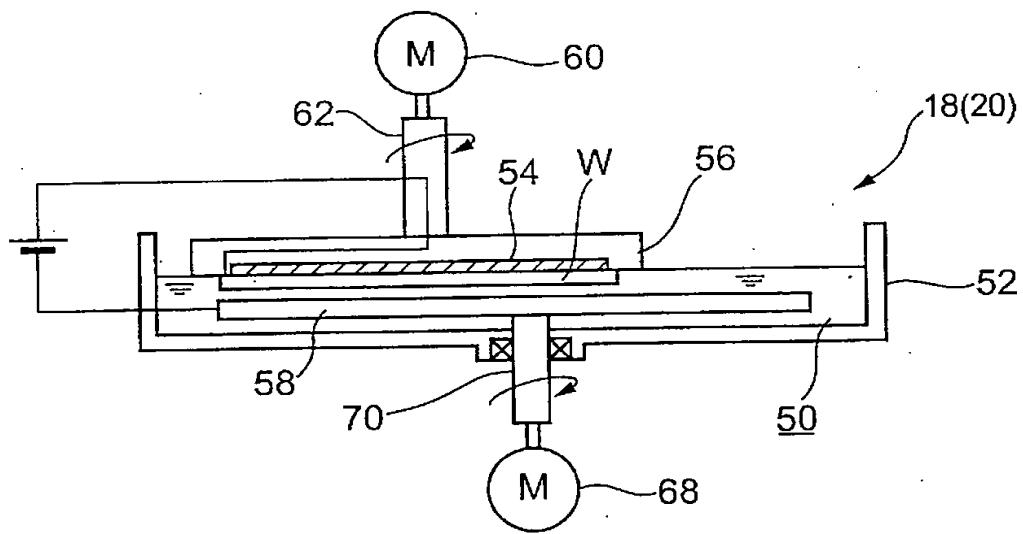
(FIG. 2)



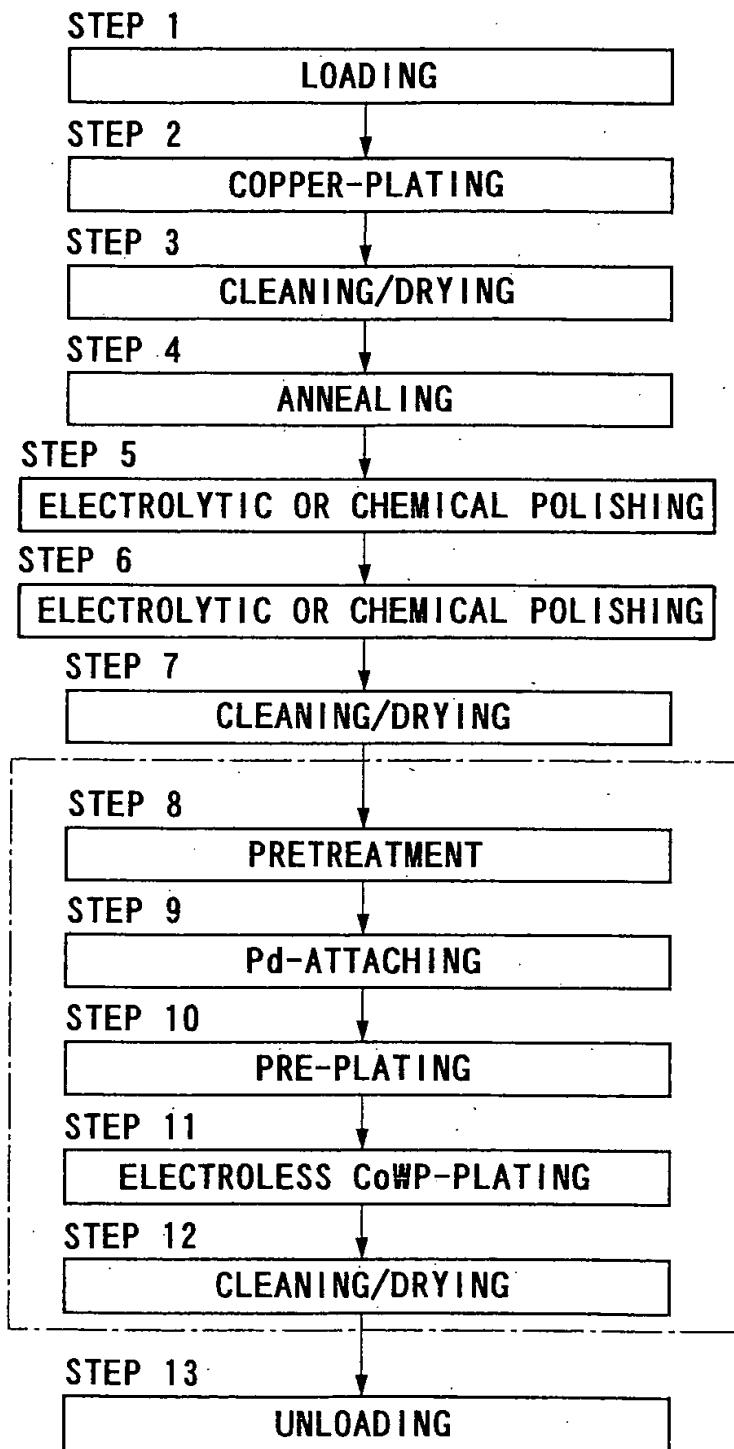
(FIG. 3)



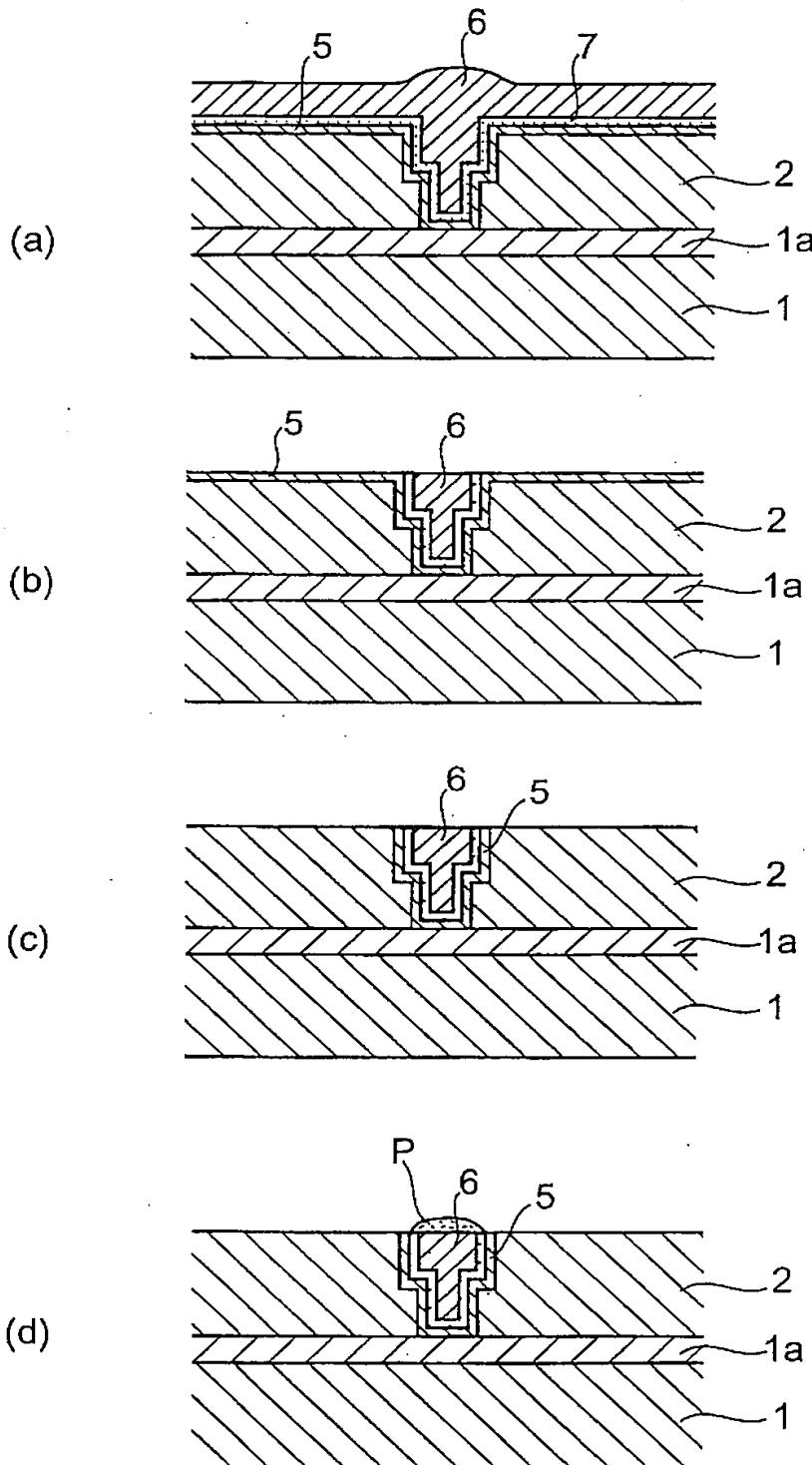
(FIG. 4)



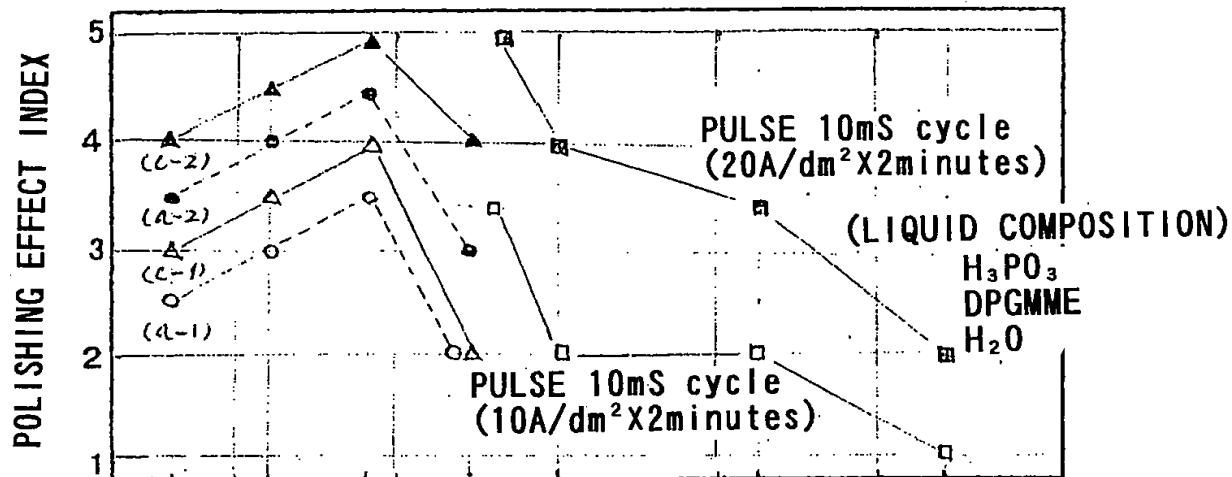
(FIG. 5)



(FIG. 6)

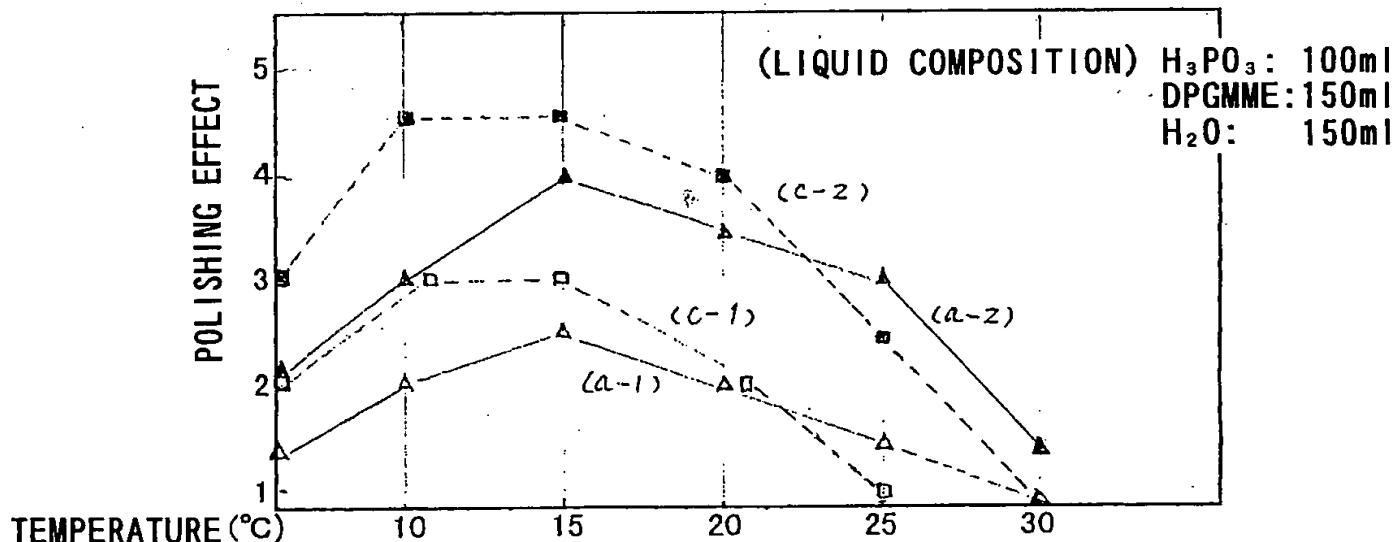


(FIG. 7)

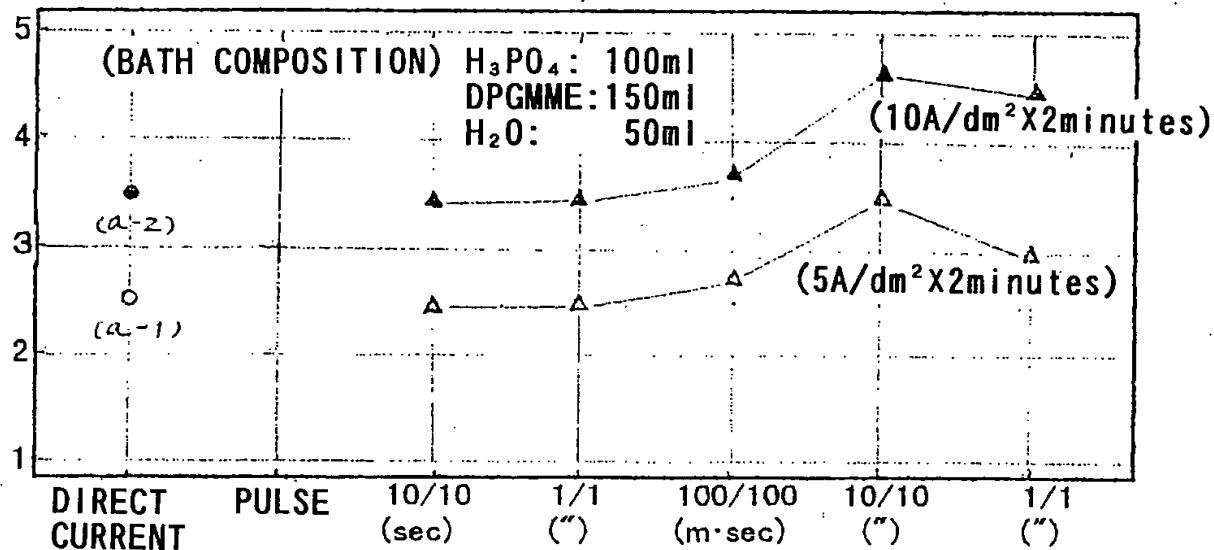


VISCOSITY (c-st) 80 56 44 33 22 12 6
 CONDUCTIVITY (mS/cm) 8 10 11 13 16 18 20

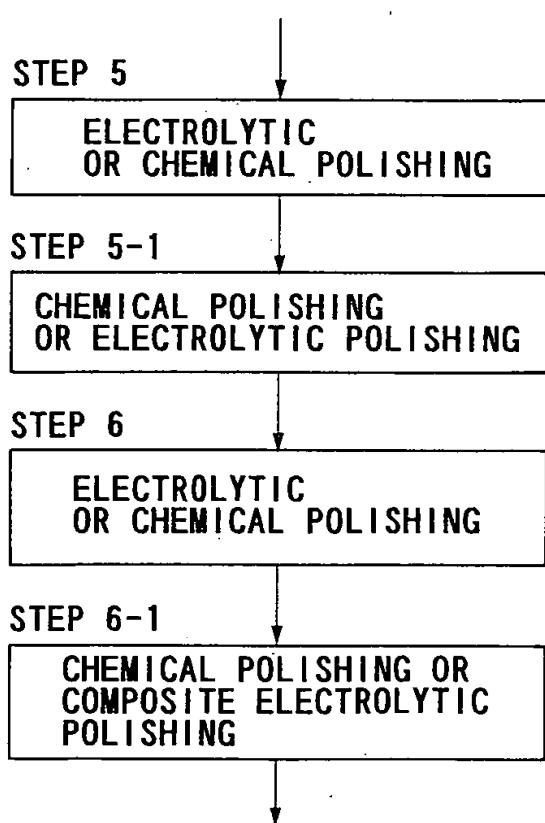
(FIG. 8)



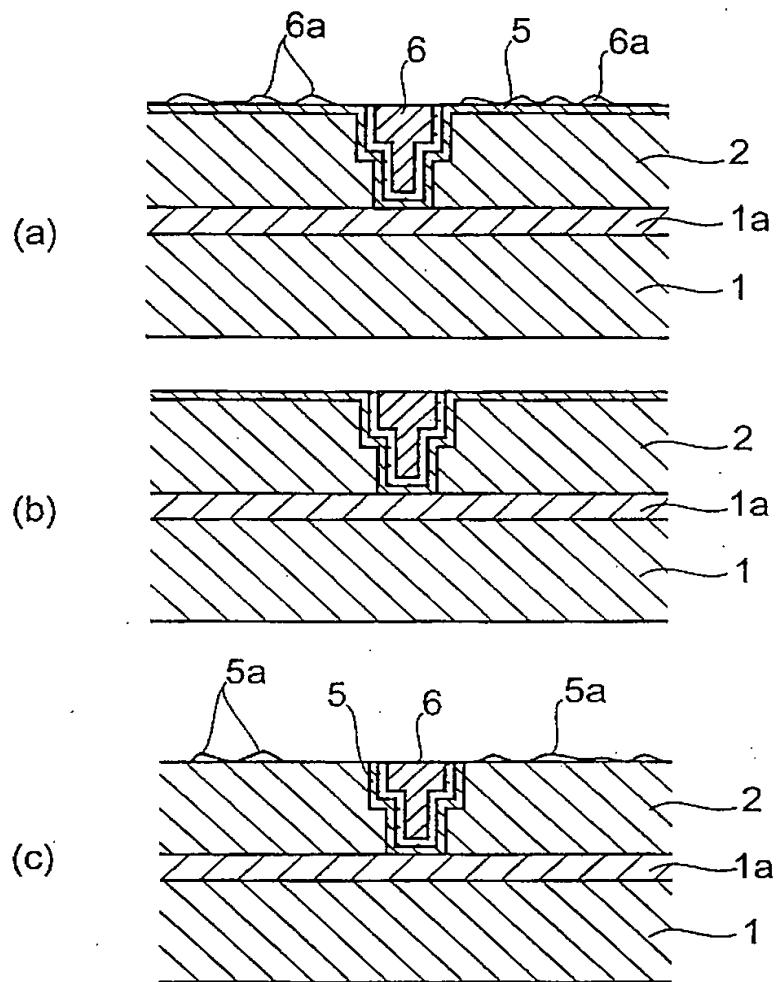
(FIG. 9)



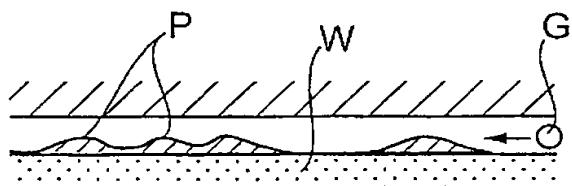
(FIG. 10)



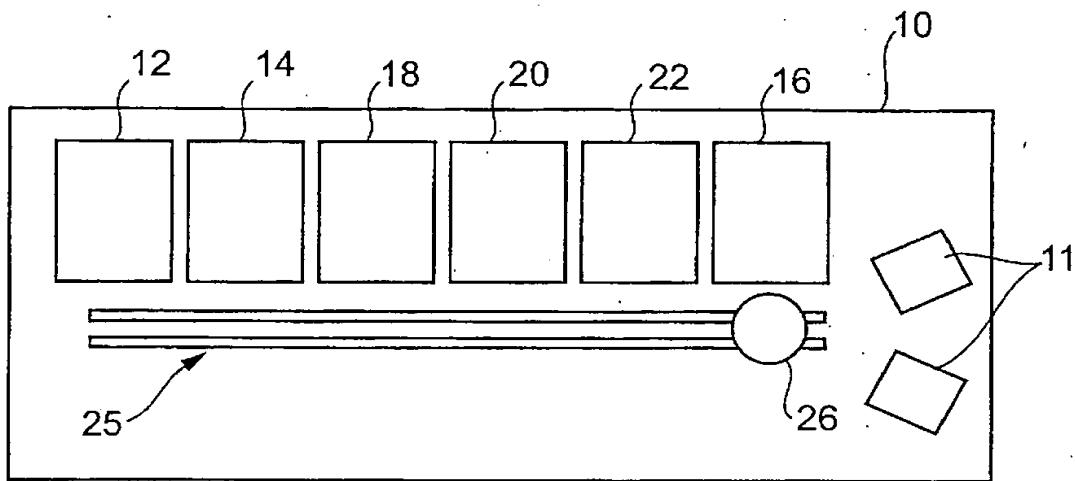
(FIG. 11)



(FIG. 12)



(FIG. 13)



(FIG. 14)

STEP 1

LOADING

STEP 2

COPPER-PLATING

STEP 3

CLEANING/DRYING

STEP 4

ELECTROLYTIC
OR CHEMICAL POLISHING

STEP 5

ELECTROLYTIC
OR CHEMICAL POLISHING

STEP 6

CLEANING/DRYING

STEP 7

ANNEALING

STEP 8

UNLOADING

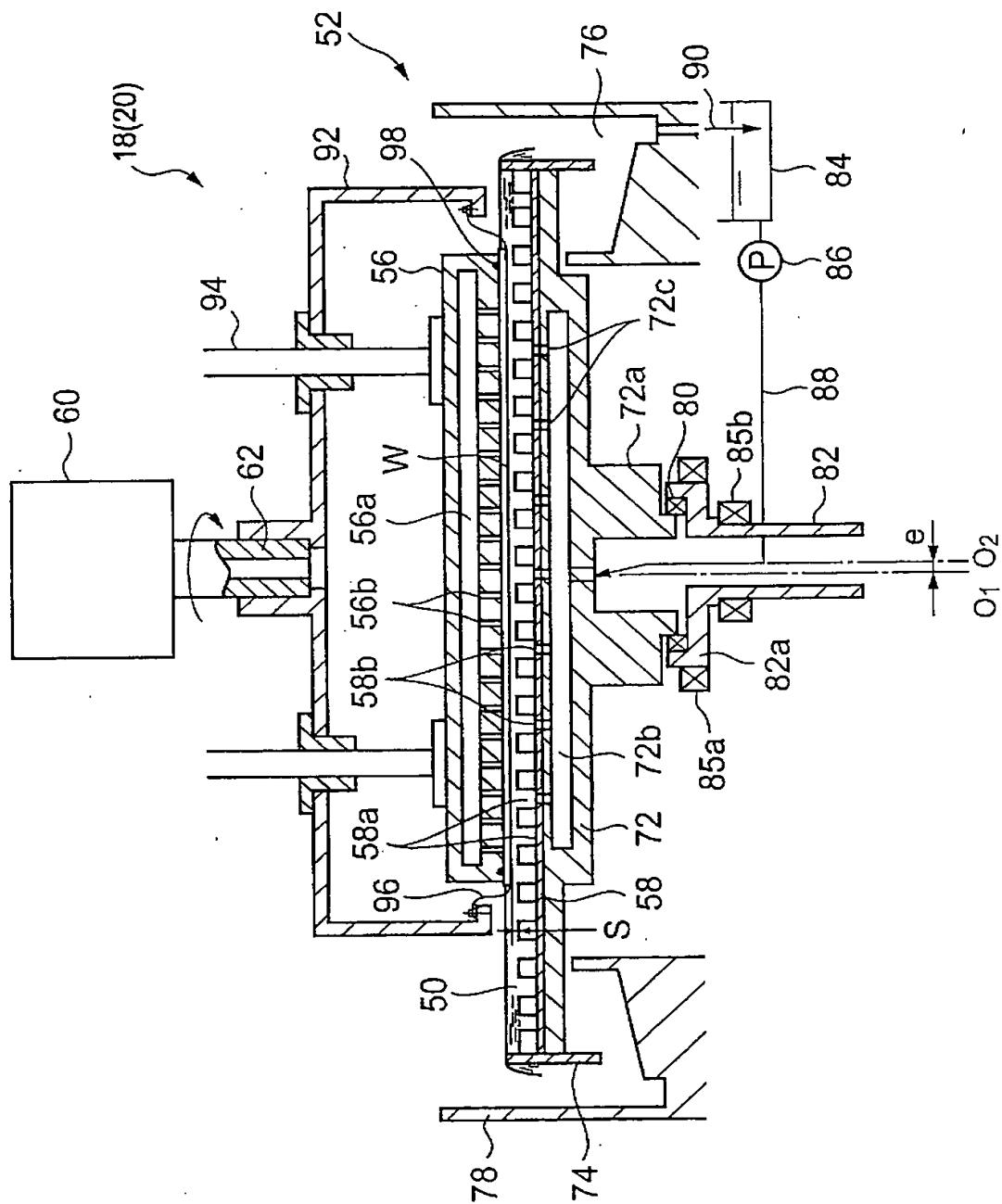
STEP 9

CMP

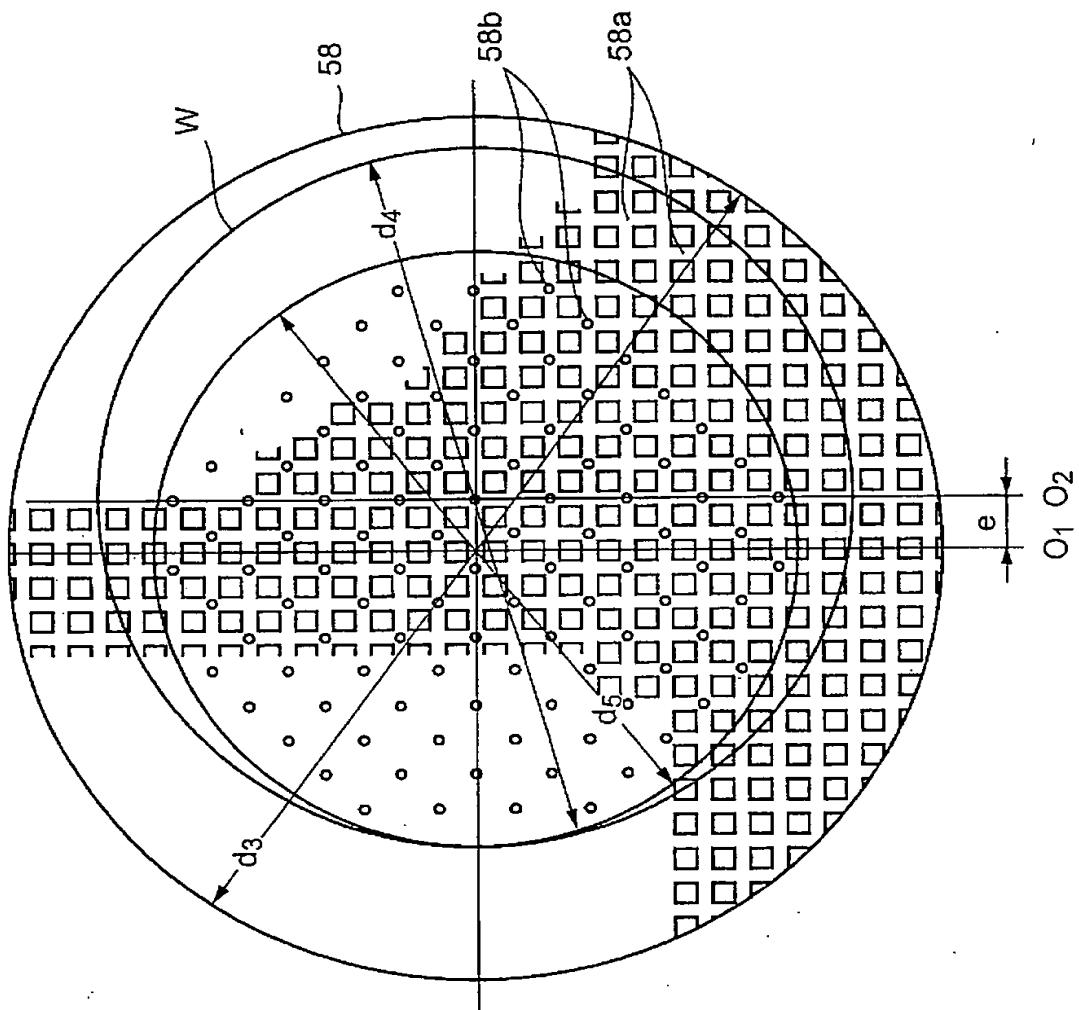
STEP 10

CAP-PLATING

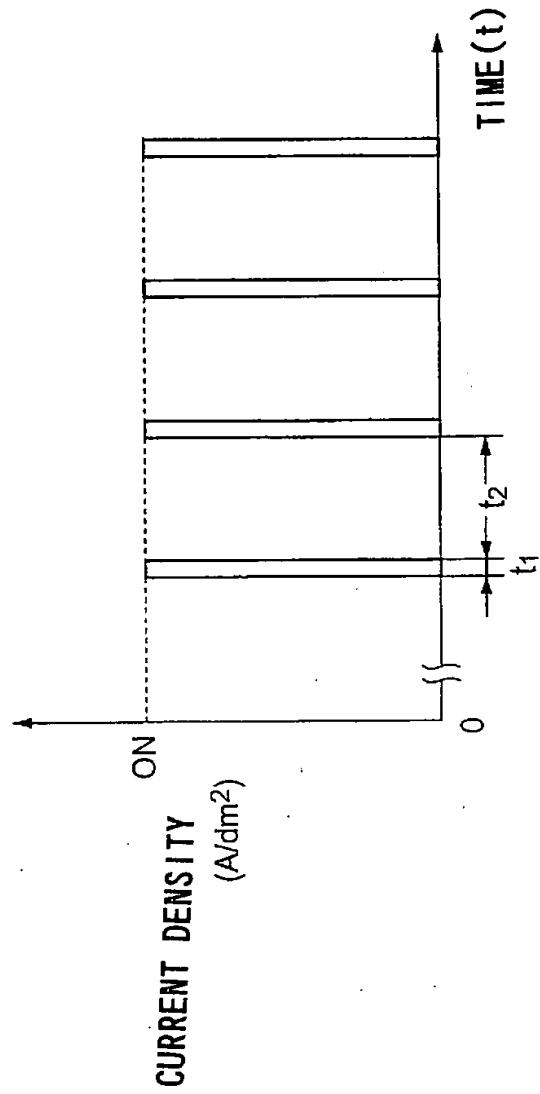
(FIG. 15)



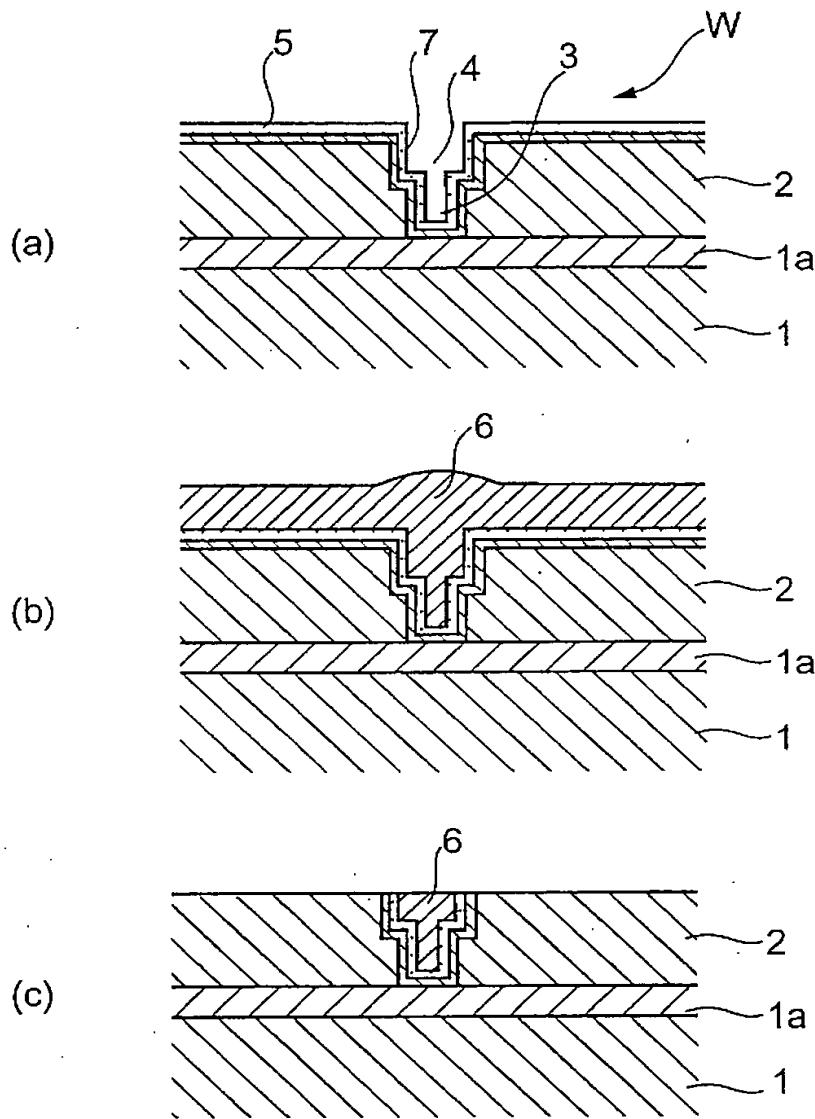
(FIG. 16)



(FIG. 17)



(FIG. 18)



(FIG. 19)

